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FUNGICIDE BENEFITS ASSESSMENT

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FUNGICIDE BENEFITS ASSESSMENT

CEREAL CROPS

January, 1991

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CATALOGING PREP

This Report Represents A Portion of the USDA/States
National Agricultural Pesticide Impact Assessment Program (NAPIAP)
Fungicide Assessment Project

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PREFACE

Plant diseases affect all the major food crops world-wide and must be controlled to prevent significant production losses and maintain food quality for animals and humans. In addition, fungicides are a necessary factor in maintaining the availability of fiber and landscape improvements ranging from forest management to enhancements through the use of ornamentals. Agricultural fungicides are a significant component in effective disease control and are critical to plant health management systems. Fungicides provide benefits to producers as well as consumers and to local as well as national economies. Farmers benefit from the prevention of yield losses, improved crop quality, enhanced market opportunities, facilitation of farmwork and harvest. Consumers also benefit from an ample, varied, safe, healthy and inexpensive food supply that is available throughout the year.

This is one of 11 separate reports that assessed the beneficial aspects of fungicide use in U.S. agriculture. The 11 reports, all using a commodity approach in evaluating fungicide use, comprise the Fungicide Benefits Assessment. This assessment represents one part of the USDA/States National Agricultural Pesticide Impact Assessment Program's Fungicide Assessment Project. The two other parts deal with (a.) a treatise examining the health and environmental factors associated with the agricultural use of fungicides, and (b.) an assessment of the status as well as the management strategies for fungal resistance to fungicides in the U.S.

The 11 Fungicide Benefits Assessment reports were prepared by a team of scientists (team leaders). The team leaders and the listing of their reports (by commodity) in the Fungicide Benefits Assessment are as follows:

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Appreciation is extended to members of the Planning Committee and many other collaborators who gave generously of their time and expertise in helping develop the project, reviewing report drafts, providing information and preparation of the various reports.

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The U.S. Department of Agriculture offers its programs to all eligible persons regardless of race, color, creed, age, gender, handicap, or national origin, and is an equal opportunity employer.

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Charles R. Curtis, Project Director
Nancy N. Ragsdale, Coordinator Representing the USDA

January, 1991

FUNGICIDE BENEFITS REPORT-CEREAL CROPS

I. **Objectives and Scope**. There were three objectives of this study. The first was to ascertain what percentage of acreage of cereal crops (wheat, rice, barley, oats, and sorghum) and hops are treated with foliar or seed fungicides each year in the United States. The second was to determine the prevalence and severity of diseases of these crops that are amenable to control with fungicides. The third was to estimate the losses caused by various diseases in the absence of fungicidal control.

II. **Background**. Information on fungicide use, disease prevalence, and yield loss was gathered from published sources where possible. Of necessity, most of the information came from unpublished assessments by plant pathologists in various states where the commodities are grown (Table 1). A broad geographic sampling of specialists was used in order to obtain data pertinent to most of the acreage of each crop. In most cases, the only information available to these specialists was what they had accumulated through contact with growers, agribusiness firms, and their own observations in their states. Organized plant disease surveys in the cereal crops are rare in the United States except for the annual rust surveys on wheat, oats, and barley conducted by the USDA Cereal Rust Laboratory. Therefore, except for rusts, it is very difficult to obtain objective data on disease incidence and severity from which accurate yield loss estimates can be made. It is equally difficult to obtain estimates of fungicide use on these crops. Foliar fungicides have not been used extensively on wheat in the past, but with the availability of registered systemic fungicides, use has increased in some areas of the country. Foliar fungicides are also used extensively on rice except in California, but even in this crop not all acreage is sprayed. A few states are conducting surveys to determine the extent of pesticide use on crops, but only the survey from Oregon was available at the time this report was written.

Table 1. Specialists who provided information about fungicide use

State	Source of information
AR	Eugene Milus, University of Arkansas, Fayetteville, AR
AR	Fleet Lee, University of Arkansas, Stutgardt, AR
CA	Mike Davis, University of California, Davis, CA
CO	William Brown, Colorado State University, Ft. Collins, CO
FL	Tom Kucharek, University of Florida, Gainesville, FL
GA	Barry Cunfer, University of Georgia, Experiment, GA
IL	Wayne Pedersen, University of Illinois, Urbana, IL
IN	James Olson, Mobay Corporation, West Lafayette, IN
KS	Doug Jardine, Kansas State University, Manhatten, KS
KY	Jim Olson, Mobay Corporation, West Lafayette, IN
LA	Clayton Hollier, Louisiana State University , Baton Rouge, LA
MI	Pat Hart, Michigan State University , East Lansing, MI
MN	Roger Jones, University of Minnesota, St. Paul, MN
MS	John Damicone, Mississippi State University, Mississippi State, MS
MT	Jack Riesselman, Montana State University, Bozeman, MT
NY	Gary Bergstrom, Cornell University , Ithaca, NY
NC	Jack Bailey, North Carolina State University, Raleigh, NC
ND	Marcia McMullen, North Dakota State University, Fargo, ND
NE	David Wysong, University of Nebraska, Lincoln, NE
OH	Pat Lipps, Ohio State University , Wooster, OH
OK	Ervin Williams, Oklahoma State University, Stillwater, OK
OR	Paul Koepsell, Oregon State University, Corvallis, OR
PA	Herb Cole, Pennsylvania State University , University Park, PA
TX	Wendell Horne (wheat, oats, sorghum) and Joseph Krauz (rice), Texas Agricultural Extension Service, College Station, TX
UT	Karen Shotwell, Utah State University, Logan, UT
WA	Roland Line, Washington State University and USDA,ARS, Pullman, WA
WA	Calvin Skotland and Dennis Johnson, Washington State University, Prosser, WA

III. Cereals

Wheat (Triticum aestivum and Triticum durum)

Wheat is grown in 42 of the 50 states in the U.S. Production areas are commonly designated by the predominant market class of wheat and agroecological features. The Great Plains is the area of bread wheat production. In the southern Great Plains, hard red winter wheat is produced. In the extreme southern part of the region, hard red spring wheats may be grown as winter wheats (i.e. they are sown in the fall and harvested in the spring). Further north, true winter wheats are grown. At the northern end of the U.S. Great Plains, winters are too severe for reliable production of winter wheat, and hard red spring wheats are grown instead. Spring durum wheats are also grown in this area. Soft red winter wheats are grown east of the Mississippi, from Florida and Louisiana to Wisconsin and Michigan. True winter wheats are grown throughout this area, but the requirements for winterhardiness vary greatly from north to south. Soft white winter wheats are grown in New York and most of Michigan. Soft white winter wheats also predominate in the Pacific Northwest. In the Intermountain region, there is a greater mix of market classes, and winter and spring types, than elsewhere. Table 2 summarizes wheat production over a six-year period in the eight agroecological zones of the continental U.S.

1. Acres planted: During the period 1981-1986, an average of 79.6 million acres of wheat were planted each year.

2. Acres harvested, production, and crop value: During the period 1981-1986, the average annual harvested area was 68.7 million acres. Average yield was 36.5 bushels per acre for a total production of 2.5 billion bushels. Six states, Kansas, North Dakota, Oklahoma, Texas, Washington, and Montana, accounted for slightly more than 50% of the total. Nineteen states accounted for 90% of the production (Minnesota, Colorado, South Dakota, Nebraska, Idaho, Missouri, California, Oregon, Illinois, Ohio, Arkansas, Indiana, and Michigan, in addition to the six states listed above). At an average grain price of $3.28, the average annual production had a farm value of $8.2 billion per year. The highest per acre yields are obtained in regions 7 and 8, followed by regions 2 and 3. Lowest per acre yields are in the major wheat producing regions (4, 5, and 6) which comprise the Great Plains. Yield potential and favorability of climate for fungal diseases of foliage

determine the extent of fungicide use in the different regions.

3. Fungicides:
Foliar fungicides. The most commonly used foliar fungicides registered for use on wheat are mancozeb (Manzate 200, Dithane M-45, and Penncozeb), propiconazole (Tilt), and triadimefon (Bayleton). Benomyl (Benlate) and thiophanate-methyl (Topsin M) are used in some states. A survey of plant pathologists in 25 states that account for 88% of total U.S. wheat acreage and represent all agroecological zones indicates that foliar fungicides are used on 6.9% of the acreage. Fungicide use is greatest in the southeastern states where foliar diseases are more consistently a problem than elsewhere in the U.S. About 31% of the acreage in this area is treated. In the northern part of the soft red winter wheat region, 11% of the acreage is treated. Use is also fairly heavy in the Pacific Northwest, although mainly for control of eyespot (*Pseudocercosporella herpotrichoides*) rather than for control of leaf diseases. In the Great Plains, the area of greatest wheat production, the use of foliar fungicides is less. For example, only 2% of the acreage in Texas is treated, less than 1% of the acreage in Oklahoma is treated, and none in Colorado is treated.

Fungicide use estimates used in this report may be artificially high, and in the future, the figures may be lower. The reason why use may have been higher in the past two years than will occur in the future is that Tilt (propiconazole) was first commercially available for wheat during the 1988 growing season. To introduce this new product to wheat growers, the manufacturer offered a money-back guarantee in 1988. If a grower did not realize enough yield benefit from using propiconazole to more than pay for the cost of application, the company would provide the grower with a comparable amount of free propiconazole the next year. In many of the wheat growing areas of the U.S., 1988 was a drought year, and there was little or no fungal foliar disease. Consequently, there was no yield response from use of propiconazole, and the manufacturer provided a great deal of free propiconazole to growers in 1989. This, plus the interest of many growers in looking at the new fungicides as a wheat production option, may have led to greater use of fungicides in 1988 and 1989 than will occur in subsequent years. Without a money-back

guarantee, growers will probably evaluate the benefits of fungicides more carefully and attempt to use them only when justified.

The newer systemic fungicides propiconazole and triadimefon do have an advantage of providing longer control than a strictly protectant fungicide, so single applications of these fungicides may make chemical control economically feasible in areas where disease pressure is high. For example, in Georgia only about 10% of the acreage was treated with fungicide when only mancozeb was available. Since triadimefon and propiconazole have become labeled, the percentage acreage treated has increased to 40-50% during the past two years when disease pressure has been great. It is expected that in years of less severe disease pressure, 20-30% of the acreage will be treated.

Mancozeb

a. Typical formulations: wettable powder, e.g. Dithane M45, Manzate 200, Penncozeb; flowable, e.g. Dithane F-45; dry flowable, e.g. Penncozeb DF.

b. Number of applications, rates, and timing: Usually one application, possibly two, 1.6 lb ai/A., applied from stem elongation until after heading, depending on diseases present and their rate of development.

c. Methods of application: aerial (more common) or ground sprayer.

d. Acres treated: This varies greatly, and there are no regional trends (Table 3). Until recently mancozeb was the only foliar fungicide available for wheat, but now labels have been issued for propiconazole and triadimefon and the manufacturers have been promoting their use. These latter fungicides have systemic activity and are often more effective than mancozeb when only a single application is used. Mancozeb may be tank-mixed with triadimefon where Septoria leaf blotches are a problem, or may be applied as a second treatment after an early treatment with propiconazole. In some areas this is essentially the only way mancozeb is still used.

e. Diseases subject to control:

Leaf, stem, and stripe rusts

(1) Disease severity and yield loss without control: Rusts are potentially a problem in all wheat-producing areas of the U.S. Warm, dry days with dew at night favor spore dispersal and germination on leaves. Under severe disease conditions yield can be reduced as much as 50% although losses of 10-15% are probably more typical in fields that are affected. Test weight may also be reduced substantially.

Each year the USDA Cereal Rust Laboratory conducts surveys throughout the U.S. to determine the incidence and severity of cereal rusts. The laboratory also obtains data from cooperators in many states. Using these data, they estimate losses in grain yield from each rust disease. For the period 1981-1986, the average annual loss of wheat to leaf rust was 2.80% for the entire country. During this same period, the average annual loss to stem rust was 0.18% and to stripe rust was 0.52%. Although these percentage losses are not great, they represent a substantial number of bushels, 76.4 million bushels per year for leaf rust, for example. All of these diseases show yearly (Table 4) and geographical variation. For the period 1981-1989, national wheat losses to leaf rust have ranged from 0.62% in the drought year of 1988 to 5.26% in 1985. In 1981 leaf rust caused greatest losses in the southeast and northwest regions of the country. In 1985 losses were again great in the southeast, and in the southern Great Plains, but losses in the Pacific Northwest were negligible.

(2) Mathematical relationship between disease intensity and yield:

Leaf rust. In experiments conducted with spring wheat in Canada during the early 1940s, Peturson et al. (1945) estimated

leaf rust severity "while the leaves were still green", and measured yield from plots in which leaf rust was allowed to develop and in which rust was controlled by frequent dustings with a sulfur fungicide. From their data, it can be calculated that percentage yield reduction increases 0.45 for each 1% leaf rust severity. Burleigh et al. (1972) developed a model based upon leaf rust assessments made at three different stages of crop development: $Y=5.3788+5.5260X_2-0.3308X_5+0.5019X_7$, in which Y is percent yield loss, X_2 is the percentage of rust on all leaves of the culm at the boot stage, X_5 is the percentage of rust on the flag leaf at the berry stage, and X_7 is the percentage of rust on the flag leaf at the early dough stage. Multiple regression models are often highly specific to the data set from which they are developed, so this model may not be generally applicable. Seck et al. (1988) developed a model: $Y=10.580+0.023ADPC_F$, in which Y is the percent loss in grain yield and $ADPC_F$ is the area under the disease progress curve for the flag leaf. The general applicability of this model is also questionable. The intercept of 10.58 indicates that with no rust, there is still a yield loss of 10.58% which although statistically valid is biologically unreasonable. Moreover, ADPC values tend to be specific to the experiment in which they are measured, because they depend not only on disease severity, but the time course over which assessments are made, and values from a study conducted in one year only, with a late-planted spring wheat, may not be generally applicable. Much of the data Seck et al. used were obtained from disease assessment in plots that were moderately resistant to leaf rust, and these lines sustained more damage for their level of disease than did the fully susceptible cultivar Thatcher. This may have been because of the high levels of exogenous inoculum in the resistant plots and consequent high numbers of infections that resulted in a hypersensitive response

which were not reflected in disease assessment data, but could have reduced yield. If only data for susceptible Thatcher are used, including those of the healthy control, the relation between percent yield reduction and ADPC on the flag leaf is Y=1.154+0.033ADPC.

Buchenau (1975) used data from fungicide trials conducted over several years with both spring and winter wheat to derive a relation between the relative area under the disease progress curve (AUDPC relative to the entire area encompassed by the severity-time axes) and percent yield reduction. In most cases, the regression coefficient was not significantly different from 1 indicating that for each percentage increase in relative AUDPC there was a one percent decrease in yield.

A general problem with yield loss models that utilize disease severities on different leaves or taken at each of several growth stages is that data in such detail are rarely available for large production areas.

Chester (1946) used data collected by various workers in the first four decades of the 20th century to develop a tabular severity-loss model (reproduced here as Table 5a). This model takes account of the fact that loss depends both on how early rust develops and how severe it becomes. It is possible that the losses in this table underestimate the situation today, because modern cultivars generally develop at a faster rate. Moreover, many of the loss functions, developed in more northern regions of the U.S. may underestimate the loss from leaf rust in Texas and other southern states because they fail to take full account of development and consequent damage arising from disease present very early in the life of the plant (Horne, personal communication).

Stem rust. Calpouzos et al. (1976) developed a graphical method for

estimating percentage yield loss in spring wheat based upon the time of epidemic onset and the rate of rust increase, calculated as the apparent infection rate. The earlier an epidemic begins and the faster its rate of increase, the greater the loss. The relationship between disease onset stage, disease increase rate, and percentage loss is nonlinear. For example, if the epidemic onset is in the early grain filling stage, the loss is about the same over a two-fold range in disease progress rate. Kirby and Archer (1927) developed a table for calculating losses to stem rust (Table 5b).

Stripe rust. Doling and Doodson (1968) used data from wheat cultivar trials conducted from 1956-1966 at several locations throughout Britain to calculate yield reduction arising from stripe rust. They found that percent yield reduction (L) was a function of stripe rust severity (R) at the completion of flowering (GS 10.5.3): $L=3R^{1/2}$. In this model, the maximum loss is 30%. If infection also occurs on glumes, the maximum loss would be greater than what is predicted by the model.

Mundy (1973) conducted a fungicide trial with cultivar Joss Cambier at one location in 1972, and obtained epidemics of various intensities. There was a linear relationship between yield, in kg/ha, and rust severity at the milk stage of grain development (GS 11.1). An analysis of data by the same procedure used by Doling and Doodson (1968) resulted in the model $L=4.87R^{1/2}$, which indicates a greater response of percent yield reduction to stripe rust than what these earlier authors found. Mundy recorded severity of rust on the upper two leaves only, whereas Doling and Doodson used rust severity for the entire culm for their model. This may account for the different slopes between the two models.

Leaf and glume blotch (*Septoria tritici* and *Stagonospora nodorum*)

(1) Disease severity and yield loss without control: This varies greatly geographically and yearly. These diseases are associated with prolonged periods of wet weather during vegetative and reproductive growth stages. The fungi persist locally on crop residues, and primary infection occurs during the fall in winter wheat. Symptoms do not normally appear on the upper leaves of the plant until after heading in the spring. Under severe disease conditions, yield can be reduced by as much as 50% although losses of 10-15% are probably more typical. Test weight may also be reduced substantially especially by the glume blotch phase of *Stagonospora* (=*Septoria*) *nodorum* infection. *Septoria tritici* tends to be the predominant pathogen when wet weather occurs in early spring while temperatures are still cool (but with daily minima above 45^0 F). If favorable moisture patterns do not occur until later in the season, *S. nodorum* is more likely to be the problem.

There is no national survey of Septoria blotch incidence and severity comparable to what is done for rusts each year by the USDA Cereal Rust Laboratory, so there is no rational basis for estimating annual losses for the country. In general, these diseases are more a greater problem in the more humid eastern wheat region and in the Pacific Northwest and less of a problem on the Great Plains. Patterson et al. (1990) estimated losses to Indiana's wheat production from various causes for the period 1956-1988 and reported that Septoria caused losses of 0.5-2% in 3 years, losses of 3-5% in 4 years, losses of 6-10% in 2 years, losses of 11-15% in 3 years, losses of 16-20% in 1 year, and losses of 21-25% in 2 years. For the 33-year period, the average annual loss was 4.2%. This figure probably applies generally to the northern part of the eastern wheat region. Losses are

probably somewhat greater in the Southeast, perhaps on the order of 6%.

(2) Mathematical relationship between disease intensity and yield: Spiertz (1973) reported disease severity data and yields for five wheat cultivars in a fungicide trial in which Septoria leaf blotches, caused by S. tritici and S. nodorum, were the only significant diseases. From these data a maximum yield can be calculated as the intercept of the linear relation between yield and disease severity. If the maximum yield for each cultivar is used to calculate a relative yield for both the sprayed and unsprayed treatments, these relative yields can be plotted against disease severity to derive a loss function. This function indicates that for each percentage severity of Septoria blotch on the upper three leaves, relative yield will decline by 0.62% (i.e. $Y=98.23-0.62S$, $R^2=0.96$). The disease severities in this model were taken 20 days after the wheat headed. King et al. (1983) using data from several locations and years in Great Britain calculated that relative yield (Y) declines about 1% for each percentage severity of leaf blotch on the flag leaf (X_1) at the mid-milk state of growth (GS 11.1): $Y=100.037-1.011X_2$. For severity on the leaf below the flag (X_2) the relation is $Y=101.303-.0551X_2$. Subsequently, Thomas et al. (1989) determined that a yield loss from infection of the leaf below the flag is 0.00265% for each degree-day accumulated from the first appearance of symptoms (degree-days calculated on a 0^0 C base). Marshall et al. (1989 and personal communication) conducted a series of experiments over three years and eight locations in Texas to measure yield reduction in wheat from infection by S. tritici. Within each experiment, epidemics of different

intensities were created with sprays of Difolatan fungicide. Based on data from 24 trials, they developed tables for the probability of loss in the range of 0-5%, 5-10%, or 10-15% based on the severity of leaf blotch at any of several growth stages ranging from GS 5 (pseudostem erection) to GS 11.2 (soft dough). They conclude that if disease has progressed at least to the leaf below the flag leaf by the time the flag leaf has emerged, a loss greater than 10% is likely. If disease has appeared on the flag leaf by the time heading is complete, it is also likely that a loss greater than 10% will be sustained.

f. Normal disease management practices: Foliar fungicides have not historically been used on wheat in the U.S. because of the low value per acre of the crop. In recent years, however, farmers using intensive crop management practices have found it profitable to use fungicides in some circumstances. Genetic resistance has been the main method of control for rusts. Increasingly, cultivars are also available that have some resistance to Septoria blotches.

g. If mancozeb were not available: Propiconazole is capable of providing control of Septoria leaf blotches almost as effectively as mancozeb. However, federal labeling restricts application to before complete emergence of the flag leaf (GS 8). This restricted application timing diminishes its effectiveness against Stagonospora nodorum which often spreads most rapidly after heading (GS 10.5). Triadimefon is not very effective against Septoria leaf blotches and indeed is usually used in combination with mancozeb where these diseases are a problem.

Triadimefon (Bayleton)

a. Typical formulations: wettable powder, Bayleton 50WP; dry flowable, Bayleton 50% DF.

b. Number of applications, rates, and timing: Usually one application,

1-4 oz. ai/A., applied when disease symptoms appear. The fungicide cannot be applied within 21 days of harvest, nor can more than 8 oz ai/acre be applied during the season.

c. Methods of application: aerial (more common) or ground sprayer.

d. Acres treated: See Table 3.

e. Diseases subject to control:

Powdery mildew (Erysiphe graminis)

(1) Disease severity and yield loss without control: In a 3-year study, Lipps and Madden (1988) measured losses of 3.2 to 14.5 bu/A (4.3 to 27.2%) depending on a cultivar's susceptibility and the favorability of weather for disease development. In North Carolina, yield reductions on the susceptible cultivar Saluda ranged from 34 to 0% depending on the environment (Leath and Bowen, 1989). Yield losses on the resistant cultivar Coker 983 in the same environments ranged from 10 to 0%. Yield reductions of 31% can be calculated from the data of Royse et al. (1980).

There is no national survey of powdery mildew incidence and severity comparable to what is done for rusts each year by the USDA Cereal Rust Laboratory, so there is no rational basis for estimating annual losses for the country. In general, powdery mildew is a problem in the more humid eastern wheat region particularly along the Atlantic Coast and in Pennsylvania and Ohio. It is rarely a problem on the Great Plains. The fungus overwinters locally and usually infects the new crop in the fall. The fungus survives the winter in infected tissue, and with the

arrival of warm weather in the spring, it begins to produce spores which cause secondary infections. In lush canopies that result from dense planting and high levels of fertilizer, the disease can become severe within the canopy without developing on the flag leaf to any great extent. Under these conditions, secondary tillers that develop later than main culms may fail to produce any grain. If humid, cloudy weather persists late in the season, infections may become severe on the upper two leaves of the plant. For the period 1956-1988, powdery mildew caused losses of 0.5-2% in 6 years, losses of 3-5% in 6 years, losses of 6-10% in 2 years, and losses of 11-15% in 3 years in Indiana (Patterson et al., 1990). For the 33-year period, the average annual loss was 2.6%. This figure probably applies generally to the northern part of the eastern wheat region except for Ohio, Pennsylvania and Virginia where losses would be greater and comparable to what is experienced in the Southeast.

(2) Mathematical relationship between disease intensity and yield: According to Large and Doling (1962), percent loss in grain yield is equal to twice the square root of the percent severity of powdery mildew on the upper four leaves after heads emerged from the boot (GS 10.5). Fried et al. (1981) used a quadratic model to relate the relative weight of grain per ear (HW) to percentage severity of powdery mildew (X) at the water ripe stage (GS 10.5.4): $HW=100-1.411X+0.0139X^2$, $R^2=0.69$.

From data of Royse et al. (1980), it can be calculated that relative yield decreases 0.63% for each 1% severity of powdery mildew on the upper four leaves at the boot stage of growth (GS 10). This study also showed that early season powdery mildew on the lower leaves has a significant effect in reducing yield. On the susceptible cultivar Saluda, relative yield declined about 1.65% for each 1% severity on the flag leaf at the mid-heading stage (GS 10.3) (Leath and Bowen, 1989). Lipps and Madden (1989a) also found that severity of powdery mildew at GS 10.3 was correlated with yield. The functional relationship was specific to each cultivar in the experiment which suggests that even in the same environment it is not possible to develop general models. Yield reductions for specific sites and cultivars ranged from 2.5% to 37.6%.

Leaf and glume blotch (Septoria tritici and Stagonospora nodorum)

(1) Disease severity and yield loss without control: See comments under the mancozeb section above. Triadimefon is not as effective against these diseases as is mancozeb. For this reason, mancozeb is often mixed with triadimefon.

(2) Mathematical relationship between disease intensity and yield: See comments in the mancozeb section above.

Leaf, stem, and stripe rusts.

(1) Disease severity and yield loss without control: See comments in the mancozeb section above.

(2) Mathematical relationship between disease intensity and yield: See comments in the mancozeb section above.

f. Normal disease management practices: See comments in the mancozeb section above regarding rusts and leaf blotches. Powdery mildew is also controlled by resistance, but in areas where this disease is consistently a problem (Ohio and Pennsylvania and down into the Southeast), only some cultivars have resistance, and there are cultivars with higher yield potential that are susceptible. _Erysiphe graminis_ is capable of overcoming simply-inherited resistance relatively quickly probably because it regularly undergoes sexual recombination in its annual life cycle. Some cultivars have a partial or "slow-mildewing" resistance that will provide some control, but under heavy disease pressure these may benefit from application of a fungicide.

g. If triadimefon were not available: Propiconazole provides control of Septoria leaf blotches more effectively than triadimefon, and about equally to a mixture of triadimefon and mancozeb. Propiconazole provides control of powdery mildew and rusts similar to triadimefon. The early cut-off time for application of propiconazole (flag leaf emergence) can reduce its effectiveness for late season infections of rusts and glume blotch.

Propiconazole (Tilt)

a. Typical formulations: emulsifiable concentrate, Tilt (41.8% ai).

b. Number of applications, rates, and timing: Only one application per season, 1.67 fl. oz. ai/A., applied as flag leaves begin to emerge (GS 8). The fungicide cannot be applied after this stage of growth.

c. Methods of application: aerial (more common) or ground sprayer.

d. Acres treated: See Table 3.

e. Diseases subject to control:

Leaf and glume blotch (*Septoria tritici* and *Stagonospora nodorum*)

(1) Disease severity and yield loss without control: See comments in the mancozeb section above. Propiconazole is not quite as effective against these diseases as mancozeb, but is superior to triadimefon.

(2) Mathematical relationship between disease intensity and yield: See comments in the mancozeb section above.

Leaf, stem, and stripe rusts.

(1) Disease severity and yield loss without control: See comments in the mancozeb section above.

(2) Mathematical relationship between disease intensity and yield: See comments in the mancozeb section above.

Powdery mildew.

(1) Disease severity and yield loss without control: See comments under triadimefon section above.

(2) Mathematical relationship between disease intensity and yield: See comments in the triadimefon section above.

f. Normal disease management practices: See comments in the mancozeb and triadimefon sections above.

g. If propiconazole were not available: A tank mixture of triadimefon and mancozeb provides control of Septoria

leaf blotches about equal to propiconazole. Triadimefon provides control of powdery mildew and rusts similar to propiconazole.

Seed treatment fungicides: Fungicidal seed treatments are common on wheat (Table 6). It is difficult to obtain estimates of the percentage of seed treated with specific fungicides, but probably the most common fungicide in use today is a mixture of carboxin and thiram (Vitavax 200). Seed treatments are mainly directed toward control of bunt and loose smut, and carboxin-thiram provides control of both. Earlier seed treatments such as quintozene and hexachlorobenzene provided control of bunt but not loose smut. Probably a high percentage of certified seed is treated with fungicide. Farmers who save their own seed may treat it themselves or have it custom-treated, but this may not be a common practice. In the eastern U.S. where an individual farmer's wheat acreage may be low and not a major component of the crop production, farmers are more likely to purchase seed from a seed dealer than to save their own. In the Great Plains and Pacific Northwest, where wheat may be the principal crop on a farm and an individual farmer will plant several hundred or more than a thousand acres, he is less likely to purchase seed except for small amounts of new cultivars.

Carboxin-thiram (Vitavax 200)

a. Typical formulations: Vitavax 200 is a flowable fungicide consisting of 17% carboxin and 17% thiram. Vitavax Pour On is a flowable fungicide for hopper box treatment consisting of 5.7% carboxin and 5.7% thiram.

b. Number of applications, rates, and timing: One application prior to planting, 0.51-0.68 fl. oz. ai/cwt.

c. Methods of application: Seed treatment, by commercial seed treater or as a hopper box application.

d. Amount of seed treated: See Table 6.

e. Diseases subject to control:

Loose smut (_Ustilago tritici_)

(1) Disease severity and yield loss without control: Loose smut can be controlled with hot water treatment, at considerable expense. Genetic resistance is available, but since the introduction of systemic fungicidal seed treatments over 20 years ago,breeders have quit breeding for resistance because of its great expense relative to the cost of seed treatment.

(2) Mathematical relationship between disease intensity and yield: Loss is directly related to the frequency of smutted heads in a field. If 10% of the heads are smutted, there will be a 10% reduction in yield.

Bunt (_Tilletia caries_ and _Tilletia foetida_)

(1) Disease severity and yield loss without control: Genetic resistance is available, but this has not been an important breeding objective because effective seed treatments have been available for about 70 years.

(2) Mathematical relationship between disease intensity and yield: Loss is directly related to the frequency of bunted heads in a field. If 10% of the heads are bunted, there will be a 10% reduction in yield. Additional loss can be incurred if the harvested grain is contaminated with spores to such an extent that the wheat acquires the bunt odor. This can lead to dockage or outright rejection at the grain elevator.

Quintozene (PCNB)

a. Typical formulations: Terra-Coat LT-2N (23.7% quintozene);
Apron-Terraclor (6.25% metalaxyl and 25% quintozene)

b. Number of applications, rates, and timing: One application prior to planting. Terracoat LT-2N is applied at 0.47 oz. ai/bu. Apron-Terraclor is applied at 0.5 oz. ai quintozene/bu.

c. Methods of application: Seed treatment.

d. Amount of seed treated: See Table 6.

Bunt (<u>Tilletia caries</u> and <u>Tilletia foetida</u>)

(1) Disease severity and yield loss without control: See comments in the carboxin-thiram section above.

(2) Mathematical relationship between disease intensity and yield: See comments in the carboxin-thiram section above.

Rhizoctonia damping-off (<u>Rhizoctonia solani</u>)

(1) Disease severity and yield loss without control: This is not a widespread problem. The fungus can also cause a root rot and sharp eyespot which are not amenable to control by seed treatment.

(2) Mathematical relationship between disease intensity and yield: None available.

Metalaxyl (Apron)

a. Typical formulations: Apron 25W;
Apron-Terraclor (6.25% metalaxyl and 25% quintozene)

b. Number of applications, rates, and timing: One application prior to planting. Apron 25W is applied at 1 oz. ai/cwt. of seed.

c. Methods of application: Seed treatment.

d. Amount of seed treated: See Table 6.

e. Diseases subject to control:

Damping-off (*Pythium aphanidermatum*, *P. debaryanum*, *P. ultimum*, *P. graminicola*, and other species)

(1) Disease severity and yield loss without control: This is very difficult to estimate because the symptoms of damping-off and browning root rot are difficult to detect and may be mistaken for other problems (soil fertility, winterkilling, etc.). The disease is more likely to be a problem when the seed bed is cold and damp, so the disease is probably of limited distribution. The causal fungi, however, are ubiquitous and have a broad host range.

(2) Mathematical relationship between disease intensity and yield: None available.

4. Disease management

a. Management practices without fungicides: Seed treatment has been used for many years for control of bunt and since the mid-1960s for control of loose smut. Without seed treatments, genetic resistance would be a possible method of control, but it would take many years to incorporate such resistance into an adequate number and diversity of cultivars. Breeding for resistance to these pathogens, especially loose smut, is very labor-intensive and time-consuming, and would divert efforts from other diseases for which the only feasible control is resistance. The hot water treatment for loose smut control could be reinstituted, but it is costly and difficult. Without seed treatments, bunt and loose smut could become

major problems in wheat production once again as they were until the latter part of the 20th century. For example, during the 1920s through the 1940s, bunt and smut were major diseases of wheat in Ohio.

The damping-off diseases are not serious problems in most wheat-producing areas. Attention to planting date, crop rotation, tillage, soil temperature and moisture can alleviate these problems.

The first line of defense against foliar fungal pathogens of wheat is the use of disease-resistant cultivars. Earliest wheat disease resistance breeding efforts in the U.S. were directed against stem rust and leaf rust. Later, incorporating resistance to powdery mildew and leaf blotches became common breeding objectives as well. Resistance still does not provide complete control of all of these diseases. In the case of rusts and powdery mildew, resistance is often transient because of genetic changes in the pathogen population that lead to evolution of new, more virulent races. Rust resistance continues to be a major breeding objective of most plant breeding programs wherever the rusts are likely to be a problem. Except in a few areas and in years when a new race of the pathogen has rendered old resistance ineffective, a grower can obtain disease control of rusts by choosing a resistant cultivar that is also high-yielding and well adapted to the area of production.

In the northern part of the eastern soft red winter wheat region there are several widely grown cultivars with excellent resistance to *Septoria tritici*. There are also many cultivars with intermediate resistance. There is no high degree of resistance to *Stagonospora nodorum* in commercially useful cultivars in the U.S. although there are differences in degree of susceptibility. It is possible to choose cultivars that have partial resistance. At any one time, only a few if any cultivars adapted to a region will have resistance to all of the fungal foliar pathogens that may cause damaging disease; therefore, fungicides may be a useful component of a crop management system. Changes in crop production practices may lead to greater disease problems. For example, the adoption of

reduced tillage as a means of reducing erosion creates more problems with Septoria blotch and powdery mildew, because the wheat residue on the soil surface harbors spores of the pathogens. However, if crop rotation is practiced in conjunction with reduced tillage, these problems can be alleviated, because even with no tillage, pathogen-infested wheat residue will not likely persist beyond the next season.

If production practices (seed bed preparation, planting, fertilization) and soil type are conducive to high yields and rainfall is frequent during the period of stem elongation, then a foliar application of fungicide at about the time of flag leaf emergence can provide some control of rusts and Septoria leaf blotches.

b. Diseases without adequate controls:
Dwarf bunt (*Tilletia controversa*), scab (*Fusarium graminearum*), and glume blotch (*Stagonospora nodorum*) frequently cause economic damage in various parts of the country and there is inadequate genetic resistance and no consistently effective and economical chemical or cultural control. Because of the early cut-off date for propiconazole application (flag leaf emergence), this fungicide may not provide protection against the glume blotch phase of *S. nodorum* infection.

Table 2. Wheat production in eight agroecological zones in the continental U.S. for the period 1981-1986.

Zone	No. of states	Area planted 1000 acres	Area harvested 1000 acres	Total Production 1000 bu	Yield bu/acre	value 1000 $
1	10	6,523	5,619	205,318	36.5	726,417
2	7	1,005	908	38,597	42.5	120,436
3	6	6,945	6,129	275,879	45.0	848,448
4	3	16,355	11,562	347,197	30.0	1,145,228
5	4	19,621	17,146	602,975	35.2	1,926,575
6	8	22,103	20,822	652,500	31.3	2,201,573
7	4	1,425	1,317	91,923	69.8	334,155
8	3	5,628	5,218	297,247	57.0	1,020,352
Total	45	79,604	68,720	2,511,635	36.5	8,323,185

Table 3. Proportion of wheat acreage in selected states that is treated with specific fungicides.

Zone	State[b]	Total production 1000 acres	Proportion of U.S. production %	Proportion of acres treated %	Acres (thousands)[a] sprayed with Mancozeb	Triadimefon	Propiconazole
1	AR	1,300	1.89	40	130	130	390
1	FL	115	0.17	15	7	7	7
1	GA	936	1.36	35	82	164	164
1	KY	483	0.70	32	37	31	114
1	LA	294	0.43	40	6	64	47
1	NC	585	0.85	2	0	0	9
2	NY	153	0.22	8	3	3	9
2	PA	220	0.32	5	0	6	6
3	IL	1,337	1.94	8	21	21	86
3	IN	958	1.39	10	34	34	24
3	MI	725	1.06	10	0	7	65
3	MO	1,783	2.59	15	67	100	100
3	OH	1,183	1.72	10	10	30	100
4	OK	5,600	8.15	<1	2	8	40
4	TX	5,467	7.96	2	22	33	55
5	CO	3,146	4.58	0			
5	KS	11,467	16.69	3	34	275	34
5	NE	2,442	3.55	3	12	12	49
6	MN	2,814	4.09	27	304	7	456
6	MT	4,833	7.03	<1			
6	ND	9,331	13.58	2	75	0	112
7	CA	898	1.31	9	40	40	0
7	UT	250	0.36	1	0	1	1
8	OR[c]	1,125	1.64	18	32	6	2
8	WA[d]	2,715	3.95	20	<1	<1	<1

[a] Acreages within a state may total more than the total sprayed, which is calculated from total acreage x percent treated, because of application of product mixtures.

[b] See Table 1 for sources of information for particular states.

[c] In Oregon, figures for mancozeb include maneb as well. In addition to the fungicides identified in the body of the table, benomyl (Benlate) is applied to 69%, thiabendazole (Mertect) is applied to 7% and thiophanate-methyl (Topsin M 4.5F) is applied to 4% of the acreage.

[d] In Washington, the principal fungicides and the percentage of sprayed acres on which they are used are: benomyl (45%), thiabendazole (45%), and thiophanate-methyl (10%).

Table 4. Annual variation in percentage losses from three rusts of wheat in the United States[a]

Year	Total production 1000 bu	Stem rust loss, %	Leaf rust loss, %	Stripe rust loss, %
1981	2,735,157	0	1.921	1.353
1982	2,756,034	0	2.567	0.103
1983	2,367,855	0.114	2.781	1.091
1984	2,550,994	0.254	1.194	0.536
1985	2,397,830	0.021	5.259	0.001
1986	2,060,767	0.681	3.048	0.026
1987	2,080,219	0.025	1.028	0.341
1988	1,786,630	0.012	0.625	0.109
1989	2,014,646	0.035	0.481	0.089

[a] Data from the U.S. Department of Agriculture Cereal Rust Laboratory, University of Minnesota, St. Paul.

Table 5a. Relation between wheat leaf rust intensity, wheat growth stage, and yield reduction[a]

Rust severity (%) at given stage of crop development

Seedling-tillering	Jointing	Boot to heading	Blossom	Milk	Dough or wax	Approximate loss from leaf rust %
		tr	10	25	40	1
	tr	10	25	40	65	3
10	25	40	65	100	100	20
25	40	65	100	100	100	35
40	65	100	100	100	100	50
65	100	100	100	100	100	70
100	100	100	100	100	100	95

[a] From Chester, K. S. 1946. The Nature and Prevention of the Cereal Rusts as Exemplified in the Leaf Rust of Wheat. Chronica Botanic Co., Waltham, Mass., 269 p.

Table 5b. Relation between wheat stem rust intensity, wheat growth stage, and yield reduction[a]

Rust severity (%) at given stage of crop development						
Boot	Flower	Milk	Soft dough	Hard dough	Mature	Loss from stem rust %
				tr	5	0
			tr	5	10	0.5
		tr	05	10	25	5
	tr	05	10	25	40	15
tr	05	10	25	40	65	50
5	10	25	40	65	100	75
10	25	40	65	100	100	100

[a] From Kirby, R. S., and Archer, W. A. 1927. Diseases of cereal and forage crops in the United States in 1926. Plant Disease Reporter Supplement 53:110-208.

Table 6. Proportion of wheat seed in selected states that is treated with fungicides

State	Percent of seed treated	Chemicals used[a]
AR	10	carboxin-thiram
CA	50	quintozene, carboxin-thiram, mancozeb
GA	15	carboxin-thiram, mancozeb, captan
IL	50	carboxin-thiram, busan
IN	76	carboxin-thiram, metalaxyl, mancozeb
KS	5	carboxin, captan
KY	58	carboxin-thiram, metalaxyl, mancozeb
LA	5	carboxin-thiram
MI	95	carboxin-thiram
MN	20	carboxin-thiram
MT	85	carboxin-thiram, maneb, quintozene, imazalil
NE	5	captan, maneb, carboxin-thiram
NY	85	carboxin-thiram
NC	0	
ND	47	carboxin-thiram, maneb
OH	70	carboxin-thiram, busan
OK	25	carboxin-thiram, quintozene, busan
OR	35	carboxin-thiram, quintozene
PA	75	carboxin, thiram, captan
TX	15	captan, quintozene, maneb, metalaxyl, imazalil, thiabendazole, carboxin-thiram
UT	80	carboxin-thiram, metalaxyl
WA		carboxin, thiram, captan

[a] See Table 1 for sources of information for particular states.

Rice (Oryza sativa L.)

Although rice is the second-ranking crop worldwide after wheat, it is grown in only a few southern states of the U.S.

1. Acres planted. An average area of 2.842 million acres was planted to rice in the U.S. during the period 1981-1986.

2. Acres harvested, production, and crop value. During 1981-1986, the average annual harvested area was 2.816 million acres. Arkansas is the leading producer of rice followed by Louisiana, California, Texas, Mississippi, and Missouri. Average yield was 4,996 pounds per acre for a total annual production of 141 million pounds. At an average price of $7.42 per hundredweight, the crop had an annual farm value of just over $1 billion.

3. Foliar fungicides. A survey of the five leading rice-producing states revealed that foliar fungicide use is common in Arkansas, Louisiana, Mississippi, and Texas but essentially nil in California. Fungicides that are used include thiabendazole (Folatec), propiconazole (Tilt), benomyl (Benlate), and iprodione (Rovral). Rice production in these four states occupies 2.525 million acres; fungicides are applied to about 900,000 of these acres, or 36% of the area.

   Benlate (benomyl)

   a. Typical formulations: wettable powder (Benlate 50 WP), dispersible granules (Benlate 50 DF).

   b. Number of applications, rates, and timing: Two applications, each at 0.5 lb ai/A., one at panicle differentiation stage and the other at 75% heading.

   c. Methods of application: 99% aerial, 1% ground.

   d. Acres treated: See Table 7.

   e. Diseases subject to control:

      Sheath blight (Rhizoctonia solani)

      (1) Disease severity and yield loss without control. In Louisiana this disease reduces yields by 8% on average, with losses in individual fields as high as 40%. Losses in Mississippi range from 10-20%. In trials in Texas, yield losses in some cultivars have been in the range of 25-40%.

      (2) Mathematical relationship between disease intensity and yield: Jones et al. (1987) conducted fungicide trials in six commercial fields in Texas which were

planted with the semidwarf rice cultivar Lemont. Disease pressure varied greatly among sites, ranging from none to severe. Where disease was severe or moderately severe, none of the fungicide treatments provided complete control of sheath blight. There also appeared to be considerable difference in yield potential among sites that was not related to sheath blight severity. For example, yields were higher in severely diseased treatments at some sites than were all yields at sites where there was not sheath blight. This makes it impossible to obtain a direct estimate of yield reduction. However, if relative yield is plotted against blight index at each location, there is a reasonably linear relation. Using the y-intercept as the potential yield at each site in the absence of blight, it is possible to calculate yield reduction from not controlling the disease. Severe disease reduced yield by 42%; moderately severe disease reduced yield by 23%. For a range of severity indexes of 2.5 to 7 on a scale of 0-9, the average decline in relative yield for each severity index unit was 0.07.

Sheath spot (Rhizoctonia oryzae)

(1) Disease severity and yield loss without control. In Louisiana this disease can reduce yields by 5%. It causes no loss in Mississippi.

(2) Mathematical relationship between disease intensity and yield: None available.

Blast (Pyricularia oryzae)

(1) Disease severity and yield loss without control: Yield losses with current control measures average 4% in Louisiana with losses in individual fields as high as 80%. Losses in severely diseased fields in Mississippi have been estimated to be 30-40%.

(2) Mathematical relationship between disease intensity and yield: Hwang et al. (1987) evaluated blast development on foliage and panicles of cultivars that differed in level of adult-plant resistance. Some plots were protected from blast with regular application of a fungicide, and others were unprotected. If the percent yield reduction (L) calculated from yields of diseased and disease-free plots is plotted against the sum of the area under the disease progress curves for blast on the leaves and the panicles (S), a linear relationship is found: $L=0.28S+3.45$, $R^2=0.94$.

f. Normal disease management practices: These include proper seeding rate and planting time, proper timing and rates of fertilizer application, water management, and the use of fungicides. Sheath blight has become more important as growers have adopted shorter-statured cultivars such as Lemont which can respond to higher rates of nitrogen fertilizer without lodging. The elimination of moldboard plowing, as a soil conservation tillage practice and as a means of reducing production costs, promotes sheath blight by favoring inoculum survival. Short-term rotations, especially to soybeans or sorghum which may also be hosts for R. solani, favors sheath blight on rice in some areas. In fields where sheath blight is a problem, crop rotations that include non hosts, low rates of nitrogen fertilizer, and lower seeding rates may help control the disease. There are no commercially adapted cultivars with adequate levels of resistance to sheath blight. Two cultivars with some degree of resistance, Newbonnet and Tebonnet, are so susceptible to blast that they cannot be profitably grown in Texas. Newbonnet has been grown successfully in Mississippi, but control of blast by benomyl is often necessary. Foliar fungicides are the primary means of control for sheath blight. The decision to use a fungicide should be based on the intensity of disease in a field as revealed by scouting just prior to the time a fungicide should be applied. In Texas, an incidence of 5% at the panicle differentiation stage of growth is considered the threshold intensity for fungicide application. According to a method developed in Mississippi, if 15% of the stops (1 stop per acre) in a field reveal any sheath blight, then a fungicide is warranted.

Jones et al. (1987) found that two applications of benomyl, at panicle differentiation and again at heading, did not give an economic return. Benomyl followed by propiconazole was profitable if no more than 5-10% of the culms were diseased at the time of initial fungicide application. Two applications of propiconazole appeared to be economically worthwhile if incidence was in the range of 10-20%. If incidence was greater than 25% at the panicle differentiation stage, none of the treatments was economical.

Blast can be controlled by use of resistant cultivars. Several cultivars adapted to the southeastern U.S. are resistant or moderately resistant to prevalent races of Pyricularia oryzae. However, resistance may be race-specific. The use of cultivars with broadly-based resistance may solve this problem, but under weather conditions very favorable for blast, their resistance may not be adequate, and some fungicide is needed to protect the

crop. In Arkansas, the leading rice cultivar, Newbonnet, is grown on a large proportion of the acreage because of its high yield potential, and growers rely on benomyl to protect it from blast.

g. If benomyl were not available: Other fungicides of equal or greater efficacy for control of sheath blight are available. However, these other fungicides (Rovral and Tilt) do not control blast. With regard to sheath blight, the impact would be more in the area of economics. Benomyl is slightly less expensive than other available products. If only benomyl were available, tolerance could develop in the pathogen population.

Tilt (propiconazole)

a. Typical formulations: emulsifiable concentrate, 41.8% active ingredients.

b. Number of applications, rates, and timing: One or two applications, depending on the rate used: Two applications of 2.5 fl. oz. ai/A., one at internode elongation to early boot, and the other when the boot is swollen; One application of 4.2 fl. oz. ai/A. at internode elongation to early boot.

c. Methods of application: 99% aerial, 1% ground.

d. Acres treated: See Table 7.

e. Diseases subject to control:

Sheath blight (Rhizoctonia solani)

(1) See comments under benomyl, above.

(2) See comments under benomyl, above.

f. See comments under benomyl, above.

g. If propiconazole were not available: Iprodione is nearly equal to propiconazole in efficacy toward sheath blight. Benomyl is inferior to these two fungicides.

Rovral (iprodione)

a. Typical formulations: wettable powder, 50% active ingredients.

b. Number of applications, rates, and timing: Two applications at 0.5 lb ai/A., one at early boot and the other at 75% heading.

c. Methods of application: 99% aerial, 1% ground.

d. Acres treated: See Table 7.

e. Diseases subject to control:

Sheath blight (Rhizoctonia solani)

(1) See comments under benomyl, above.

(2) See comments under benomyl, above.

f. See comments under benomyl, above.

g. If iprodione were not available: Other fungicides of nearly equal or better efficacy are available.

Seed treatments (several different fungicides)

a. Chemicals and rates of application:

Apron Fl	0.75 to 1.5 oz./cwt.
Apron 25 WP	1-2 oz./cwt.
Champion SD	4-8 oz./cwt.
Dithane F-45	3.2-6.4 oz./cwt.
Dithane DF	2.1-4.3 oz./cwt.
Gustafson 42S	3.3 oz./cwt.
Kocide SD	4.8 oz./cwt.
Manex II	3.4-6.7 oz./cwt.
Manzate 200 DF	2-4 oz./cwt.
Vitavax 200	4 oz./cwt.

b. Amount treated: See Table 8.

c. Diseases subject to control:

Seed and seedling blights.

(1) Yield loss without control: 20%.

(2) Mathematical relationship between disease intensity and yield: None available.

f. Normal disease management practices: Treat seed and do not plant during cool weather.

g. If seed treatment fungicides were not available: Stand failures would increase tremendously.

4. State recommendations.

   Use resistant cultivars and good cultural practices (see details under item f in the benomyl section.

5. Diseases without adequate controls: kernel smut.

Table 7. Proportion of rice acreage in selected states that is treated with specific fungicides

State[b]	Total production acres	Proportion of U.S. production %	Proportion of acres treated %	Area treated with specific fungicides: Name	Area treated with specific fungicides: Acres(1000)[a]
AR	1171	41.58	50	Benomyl	380
				Propiconazole	146
				Iprodione	58
CA	443	15.73	0		
LA	511	18.14	30	Benomyl	80
				Propiconazole	80
				Iprodione	20
MS	250	7.81	40	Benomyl	50
				Propiconazole	30
				Iprodione	20
TX	400	14.20	40	Benomyl	16
				Propiconazole	128
				Iprodione	16

[a] Acreages within a state may total more than the total sprayed which is calculated from total acreage x percent treated because of application of product mixtures.

[b] See Table 1 for sources of information for particular states.

Table 8. Proportion of rice seed in selected states that is treated with fungicides

State	Percent of seed treated	Chemicals used[a]
AR	30	
CA	80	copper, captan, busan, mancozeb, metalaxyl
LA	100	metalaxyl, copper, mancozeb, maneb, carboxin, thiram
TX	100	captan, carboxin, thiram, quintozene, terrazole, metalaxyl

[a] See Table 1 for sources of information for particular states.

Barley (_Hordeum vulgare_ L.)

1. Acres planted. An average area of 11.293 million acres was planted to barley in the U.S. during the period 1981-1986.

2. Acres harvested, production, and crop value. During 1981-1986, the average annual harvested area was 10.438 million acres. North Dakota, Montana, and Idaho are the leading producers of barley followed by Minnesota and Washington. These five states account for 72% of the U.S. barley acreage. Altogether, the USDA reports barley production in 29 states. Average yield for 1981-1986 was 52.7 bushels per acre for a total annual production of 550 million bushels. At an average price of $2.10 per bushel, the crop had an annual farm value of about $1,152 million.

3. Foliar fungicides. A survey of several barley-producing states revealed that use of foliar fungicides is minimal on barley.

   Bayleton (triadimefon)

   a. Typical formulations: wettable powder, Bayleton 50WP; dry flowable, Bayleton 50% DF.

   b. Number of applications, rates, and timing: Usually one application, 1-4 oz. ai/A., applied when disease symptoms appear. The fungicide cannot be applied within 21 days of harvest, nor can more than 8 oz. ai/A. be applied during the season.

   c. Methods of application: aerial (more common) or ground sprayer.

   d. Acres treated: See Table 9.

   e. Diseases subject to control:

      Scald (_Rhynchosporium secalis_)

      (1) Disease severity and yield loss without control: Yield losses can be as high as 40%, but losses in the range of 1-10% are more typical (Mathre, 1982).

      (2) Mathematical relationship between disease intensity and yield: Khan and D'Antuono (1985) determined that percent loss in grain yield (L) in spring barley was related to percent severity of scald (D) on the upper three leaves at the mid-milk stage (GS 11.1) of growth according to the equation: $L=1.83+0.318D$.

Powdery mildew (Erysiphe graminis)

(1) Disease severity and yield loss without control. This disease is not a problem in the major barley growing areas of the U.S. because of the low humidity in these regions.

(2) Mathematical relationship between disease intensity and yield: Large and Doling (1962) calculated that percent yield reduction was equal to about 2.5 times the square root of percent severity of mildew on the upper four leaves of the stem when all heads had emerged (GS 10.5).

Leaf rust (Puccinia hordei)

(1) Disease severity and yield loss without control. The disease rarely causes economic loss in the major U.S. barley growing areas.

(2) Mathematical relationship between disease intensity and yield: Similar to leaf rust of wheat.

f. Normal disease management practices: Genetic resistance is available for control of scald and leaf rust. Elimination of the source of primary inoculum of scald can be achieved by plowing or burning of stubble although these practices may not be compatible with soil erosion control practices.

g. If Bayleton were not available: Other fungicides of greater efficacy for control of scald, powdery mildew and leaf rust are available. Considering the small proportion of U.S. barley acreage treated with foliar fungicides, and the availability of resistance to rusts and scald, the curtailment of fungicide use on this crop would probably not have a significant effect on overall production although production in certain environments might be adversely affected.

Tilt (propiconazole)

a. Typical formulations: emulsifiable concentrate, Tilt (41.8% ai).

b. Number of applications, rates, and timing: Only one application per season, 1.67 fl. oz. ai/acre, applied as flag leaves begin to emerge (GS 8). The fungicide cannot be applied after this stage of growth.

c. Methods of application: aerial (more common) or ground sprayer.

d. Acres treated: See Table 9.

e. Diseases subject to control:

Scald (*Rhynchosporium secalis*)

(1) Disease severity and yield loss without control: See comments under Bayleton above.

(2) Mathematical relationship between disease intensity and yield: See comments under Bayleton above.

Powdery mildew (*Erysiphe graminis*)

(1) Disease severity and yield loss without control. See comments under Bayleton above.

(2) Mathematical relationship between disease intensity and yield: See comments under Bayleton above.

Leaf rust (*Puccinia hordei*)

(1) Disease severity and yield loss without control. See comments under Bayleton above.

(2) Mathematical relationship between disease intensity and yield: See comments under Bayleton above.

Mancozeb

a. Typical formulations: wettable powder, e.g. Dithane M45, Manzate 200, Penncozeb; flowable, e.g. Dithane F-45; dry flowable, e.g. Penncozeb DF.

b. Number of applications, rates, and timing: Usually one application, possibly two, 1.6 lb ai/acre, applied from stem elongation until after heading, depending on diseases present and their rate of development.

c. Methods of application: aerial (more common) or ground sprayer.

d. Acres treated: See Table 9.

e. Diseases subject to control:

Scald (*Rhynchosporium secalis*)

(1) Disease severity and yield loss without control: See comments under Bayleton above.

(2) Mathematical relationship between disease intensity and yield: See comments under Bayleton above.

Leaf rust (Puccinia hordei)

(1) Disease severity and yield loss without control. See comments under Bayleton above.

(2) Mathematical relationship between disease intensity and yield: See comments under Bayleton above.

Vitavax (carboxin-thiram)

a. Typical formulations: Vitavax 200 is a flowable fungicide consisting of 17% carboxin and 17% thiram. Vitavax Pour On is a flowable fungicide for hopper box treatment consisting of 5.7% carboxin and 5.7% thiram.

b. Number of applications, rates, and timing: One application prior to planting, 0.51-0.68 fl. oz. ai/cwt.

c. Methods of application: Seed treatment, by commercial seed treater or as a hopper box application.

d. Amount of seed treated: See Table 10.

e. Diseases subject to control:

Smut: covered, loose, and semiloose (Ustilago hordei, U. avenae and U. nigra)

(1) Disease severity and yield loss without control: Loose smut can be controlled with hot water treatment at considerable expense. Genetic resistance is available, but since the advent of systemic fungicidal seed treatments, breeders have quit breeding for resistance because of its great expense relative to the cost of seed treatment.

(2) Mathematical relationship between disease intensity and yield: Loss is directly related to the frequency of smutted heads in a field. If 10% of the heads are smutted, there will be a 10% reduction in yield.

Table 9. Proportion of barley acreage in selected states that is treated with specific fungicides.

State[b]	Total production acres	Proportion of U.S. production %	Proportion of production treated %	Area treated with specific fungicides Name	Acres[a]
CA	505	4.34	1	Bayleton	2.5
				Mancozeb	2.5
KS	144	1.38	0		
MI	37	0.35	1	Tilt	0.2
				Bayleton	0.2
MN	959	9.19	20[c]	Tilt	191.8
MT	1,753	16.80	1	Tilt	17.6
NE	76	0.73	1	Tilt	
				Mancozeb	
ND	2,712	25.98	1	Tilt	16.3
				Mancozeb	10.8
OR	287	2.75	1	Bayleton	2.9
				Mertect 340F	2.9
UT	157	1.50	0		

[a] Acreages within a state may total more than the total sprayed which is calculated from total acreage x percent treated, because of application of product mixtures.

[b] See Table 1 for sources of information for particular states

[c] Tilt was applied to about 200,000 acres in Minnesota when the fungicide was introduced, under Ciba Geigy's guarantee program. This level of use will probably not continue because for lack of yield response to fungicide use.

Table 10. Proportion of barley seed in selected states that is treated with fungicides.

State	Percent of seed treated	Chemicals used [a,b]
CA	50	quintozene (90), imazalil (5), carboxin-thiram (5)
GA	15	carboxin-thiram, mancozeb, captan
MI	95	carboxin-thiram
MN	50	carboxin-thiram, maneb, captan
MT	85	carboxin-thiram (60), maneb (20), quintozene (10), imazalil (10)
ND	51	carboxin-thiram, maneb
OR	100	thiram, quintozene, captan
PA	20	captan, thiram
TX	5	captan, thiram, metalaxyl, maneb, carboxin, quintozene, terrazole, imazalil

[a] See Table 1 for sources of information for particular states.

[b] Where estimates are available, the percentage of treated seed that is treated with a specific fungicide is given in parentheses after the name of the fungicide.

Oats (<u>Avena</u> <u>sativa</u> L.)

1. Acres planted. An average area of 14.663 million acres was planted to oats in the U.S. during the period 1981-1986.

2. Acres harvested, production, and crop value. During 1981-1986, the average annual harvested area was 8.659 million acres. The disparity between acres planted and acres planted for grain is because many oats are grazed out or used as a cover crop on set-aside land. South Dakota and Minnesota are the leading producers of oats followed by North Dakota, Wisconsin, and Iowa. These five states account for 63% of the U.S. oat acreage. Altogether, the USDA reports oat production in 36 states. Average yield for 1981-1986 was 56.9 bushels per acre for a total annual production of 493 million bushels. At an average price of $1.53 per bushel, the crop had an annual farm value of about $752 million. For the past several years, the U.S. has imported about 60 million bushels of milling oats annually.

3. Foliar fungicides. A survey of several oat-producing states revealed that foliar fungicide use is nil on oats (Table 11). The main fungal foliar diseases of this crop are crown and stem rusts, and these are controlled by genetic resistance. Even in situations where resistance is not effective, because races of the pathogen overcome the genetic resistance of the cultivars being grown, the price of oats does not justify the expense of foliar fungicide treatments. Seed treatments are used on some oats (Table 12).

Table 11. Proportion of oat acreage in selected states that is treated with specific fungicides

State[b]	Total production acres	Proportion of U.S. production %	Proportion of production treated %	Area treated with specific fungicides Name	Acres[a]
CA	49	0.56	0		
KS	162	1.87	0		
MI	350	4.04	0		
MN	1,243	14.36	0		
NE	378	4.36	1	Tilt Mancozeb	
NY	227	2.62	0		
NC	69	0.80	0		
ND	965	11.14			
OH	257	2.97	0		
OR	80	0.92	0		
TX	325	3.75	0		
UT	13	0.15	0		

a Acreages within a state may total more than the total sprayed which is calculated from total acreage x percent treated because of application of product mixtures.

b See Table 1 for sources of information for particular states

Table 12. Proportion of oat seed in selected states that is treated with fungicides.

State	Percent of seed treated	Chemicals used [a]
CA	25	quintozene (100)
GA	15	carboxin-thiram, mancozeb, captan
MI	95	carboxin-thiram
ND	29	carboxin-thiram, maneb
OH	35	carboxin-thiram
OR	15	carboxin-thiram
PA	5	captan, thiram
TX	5	captan, quintozene, metalaxyl, carboxin-thiram, maneb

[a] See Table 1 for sources of information for particular states.

Sorghum (<u>Sorghum</u> <u>bicolor</u> (L.) Moench.)

1. Acres planted. An average area of 15.752 million acres was planted to sorghum in the U.S. during the period 1981-1986.

2. Acres harvested, production, and crop value. During 1981-1986, the average annual harvested area was 13.949 million acres. Texas, Kansas, Nebraska, and Missouri are the leading producers of sorghum. These four states account for 76% of the U.S. sorghum acreage. Altogether, the USDA reports sorghum production in 23 states. Average yield for 1981-1986 was 60.5 bushels per acre, for a total annual production of 853 million bushels. At an average price of $2.32 per bushel, the crop had an annual farm value of about $1,976 million.

3. Foliar fungicides. A survey of several sorghum-producing states revealed that foliar fungicide use is nil on sorghum.

Table 13. Proportion of sorghum acreage in selected states that is treated with specific fungicides.

State[a]	Total production acres	Proportion of of U.S. production %	production treated %
CA	53	0.38	0
KS	3,718	26.65	0
NE	1,703	12.21	0

[a] See Table 1 for sources of information for particular states

Hops (_Humulus lupulus_ L.)

1. Acres planted. Information not available.

2. Acres harvested, production, and crop value. During 1981-1986, the average annual harvested area was 34 thousand acres. Washington, Oregon, Idaho, and California are the states in which hops are produced. Production in Washington accounts for 70% of the acreage. Average yield for 1981-1986 was 1,873 pounds per acre, for a total annual production of 63.5 million pounds. At an average price of $1.84 per pound, the crop had an annual farm value of about $116.6 million.

Ridomil (metalaxyl)

a. Typical formulations: Ridomil 2E (25.1% ai)

b. Number of applications, rates, and timing: In Washington, usually one application, infrequently two, depending on favorability of weather for disease; 1.0 lb ai/acre.

c. Methods of application: Ground application, in strips to rootstocks. Foliar application of metalaxyl plus copper is now registered and used. Growers prepare their own tank mixes and make one application per year.

d. Acres treated: See Table 14.

e. Diseases subject to control:

Downy mildew (_Pseudoperonospora humuli_)

(1) Disease severity and loss without control: See section 5 below.

(2) Mathematical relationship between disease intensity and yield: See section 5 below.

Kocide

a. Typical formulations: Copper hydroxide

b. Number of applications, rates, and timing: One application, 1.5 lb ai/acre.

c. Methods of application: See above

d. Acres treated: See Table 14.

e. Diseases subject to control:

Downy mildew (Pseudoperonospora humuli)

(1) Disease severity and loss without control: See section 5 below.

(2) Mathematical relationship between disease intensity and yield: See section 5 below.

f. Normal disease management practices: See section 5 below.

g. If copper were not available: There is concern about the evolution of strains of the fungus resistant to metalaxyl if this were to be the only fungicide used.

4. Federal/State recommendations: Sanitation (removal of diseased tissue, use of disease-free planting stock), cultural practices (pruning as late as possible in the spring), use of resistant cultivars, and a fungicide spray program will provide effective control.

5. Disease management: Hops are a perennial crop. The downy mildew fungus overwinters as mycelium in infected crowns (Skotland and Johnson, 1983). These infected crowns give rise to stunted chlorotic "primary" spikes which provide inoculum for infection of healthy shoots. Severe epidemics occur about one in three years in the Yakima Valley of Washington (Johnson et al., 1988). In most years, there is only a brief time during May for secondary infections to take place. By June, conditions are normally too dry and hot for inoculum production and infection. In the Willamette Valley of Oregon, climate is more conducive to disease. The greatest damage from downy mildew in drier environments is from crown death; in wetter climates where cultivars with resistance to crown infection are grown, loss is from cone infection.

Cultivars differ in resistance, and in areas with weather regularly conducive to the disease, susceptible cultivars such as the Cluster types are avoided if possible. Because of strict flavor requirements by the brewing industry, some resistant cultivars may not be suitable or may be suitable in only certain environments. Cultivars with partial resistance (e.g. Bullion, Brewers Gold, and Cascade) that are grown in mildew-prone areas still require some fungicide spray during the season for effective disease control. Removing primary spikes can be an effective method for retarding secondary infections and improves the efficacy of chemical control. Late pruning retards shoot development with the consequence that new shoots develop later in the season when weather is less likely to be favorable for mildew. In several European countries, weather-based forecasts have been developed for the fungicidal management of hop downy mildew, but these have not worked well in Washington, perhaps because of the greater susceptibility of the Cluster cultivars. A model

developed in Washington that monitors the appearance of primary spikes and uses weather data to predict the favorability of weather for secondary infection has worked better.

Table 14. Proportion of hops acreage in selected states that is treated with specific fungicides

State[a]	Total production acres	Proportion of U.S. production %	Proportion of production treated %	Area treated with specific fungicides Name	Acres
CA	1,000	2.94	0		
OR	5,350	17.65	57	Copper	2,700
				Metalaxyl	3,400
WA	24,600	70.6	25	Copper	600
				Metalaxyl	5,500

a See Table 1 for sources of information for particular states.

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V. Conclusions

Nationally, foliar fungicide use is limited on the cereals. It is practically nil on barley, oats, and sorghum. The low per-acre value of these crops along with the fact that their major areas of production are in areas where foliar disease problems are less serious (except for rusts on oats) contribute to this situation. Genetic resistance has been the main means of control of the rusts in oats, barley and wheat; therefore, except in certain situations where effective resistance is not available, fungicides have not been used to control these diseases.

Less than 7% of the U.S. wheat acreage receives foliar fungicides. However, in certain regions of the country, especially the Southeast and Pacific Northwest, the percentage of treated acreage is much higher. This is a consequence of the higher yield potential in these areas compared to the major wheat producing regions of the southern and northern Great Plains and the greater disease pressure in these areas. This disease pressure results from the milder winters and longer and often wetter growing seasons that favor the development of fungal pathogens of wheat. The geographical pattern of use also reflects the diseases that are problems in different parts of the country. In the Pacific Northwest, most of the foliar fungicide treatments are directed toward control of eyespot which is not a serious problem in other parts of the country and for which there is not adequate genetic resistance in adapted cultivars. In the Southeast, Septoria blotches and powdery mildew are often severe. Although there is some resistance to Septoria blotch, many cultivars are susceptible, and few cultivars have a sufficient degree of resistance to sustain no loss in grain yield and quality under conditions very favorable for disease as often occurs in the South. Powdery mildew can be controlled with genetic resistance, but resistance conferred by single genes is notoriously ephemeral owing to the rapidity with which the fungus can evolve to overcome this resistance. Rusts can occur anywhere in the U.S. and have traditionally been the most important diseases in the Great Plains. More effort has gone into breeding cultivars with rust resistance than has gone into breeding resistance for any other disease. Consequently, cultivars grown on much of the U.S. wheat acreage have a useful degree of resistance to stem rust. Less of the U.S. wheat acreage is protected against leaf rust by genetic resistance, and over the past decade losses have been greater to this rust than to stem rust. Stripe rust is usually confined to the Pacific Northwest, and here also there are many cultivars available that have resistance.

In the humid southeastern U.S. and Texas, rice is afflicted with sheath blight and blast. Although resistance is available to most of the more common races of *Pyricularia oryzae* in the United States, adequate resistance to sheath blight is lacking. Many of the cultivars with highest yield potential are susceptible to one or another of these diseases, and growers find it economical to grow these cultivars and use a fungicide rather than to grow a resistant cultivar.

In both wheat and rice, breeders are working continually to incorporate resistance to all important diseases into cultivars that have high yield

potential and good grain quality. This is a difficult challenge and in some cases partial resistance may be all that is available or may be a better choice to avoid the genetic vulnerability that arises from the use of high levels of resistance that are typically conferred by single genes. The strategy of using durable but partial resistance will be more effective if it can be part of a disease management system that includes the option of using fungicides in years or localities that are especially favorable for disease development.

In the case of wheat especially, although fungicides currently have a minor impact on national production, they are quite important for certain regions of the country. Where they are used in the Pacific Northwest for eyespot control, wheat is the major, and in many cases, the only crop grown. In the Southeast and up into the northern part of the eastern soft wheat region, wheat yield potential is much higher than in the Great Plains, and wheat provides an excellent rotational crop. This part of the country is the major supplier of soft wheats which have different end-product uses than the hard wheats which are grown in the Great Plains.

The main use of EBDCs on cereals is in the form of mancozeb on wheat. Although there would be no dire consequences to U.S. wheat production if use of this product were canceled, it is an effective component of an integrated program of wheat disease management. It is the most economical of the foliar fungicides registered for use on wheat and is more effective, considering inherent efficacy and restrictions on timing and number of applications, than other fungicides for control of late-season infections by rusts and *Stagonospora nodorum*.

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